National Aeronautics and Space Administration

Architectures for Human Exploration of Near Earth Asteroids

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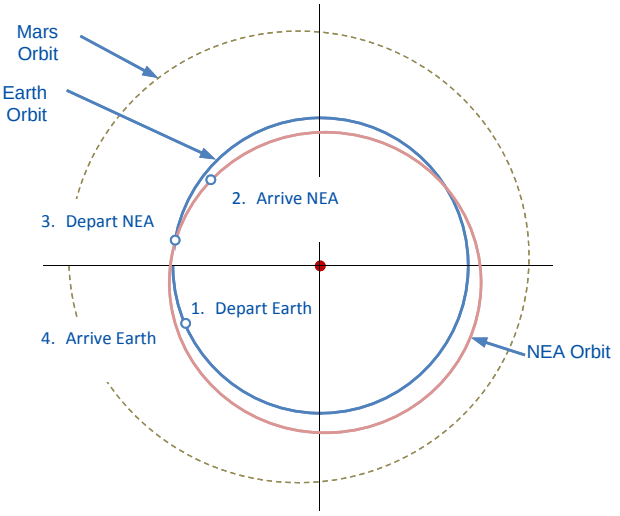
Human Exploration of NEAs Key Factors

- **Challenges of supporting humans for long-durations in deep-space**
  - How short can the trip times be reduced in order to reduce crew exposure to the deep-space radiation and micro-gravity environment?
- **Incorporation of advanced technologies**
  - Are there options to conduct easy, early missions?
  - What is the affect of infusion of advanced propulsion technologies on target availability
- **Mission design constraints:**
  - When do the departure opportunities open up?
  - How frequent are they?
  - How long is the departure window
- **How many launches are required to conduct a round trip human mission to a NEA**



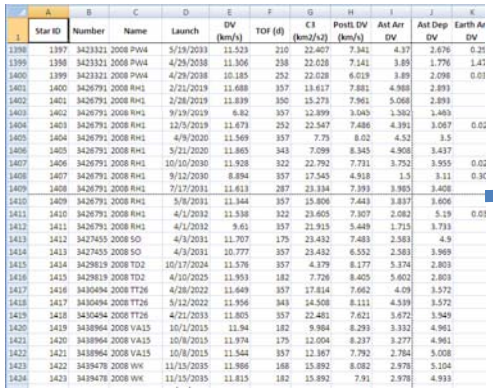
Overview

- **NHATS [Near-Earth Asteroid (NEA) Human Space Flight (HSF) Accessible Targets Study] trajectory scans by both the GSFC and JPL teams produced millions of potential trajectories to thousands targets**
- **Of those millions of trajectories, thousands may represent "good" candidate mission opportunities**
- **Several different transportation technologies considered, including**
  - All chemical propulsion
  - Nuclear Thermal Propulsion (NTR)
  - Electric Propulsion (Solar Electric) for the deep space portion of the mission
  - Hybrid Propulsion as characterized by chemical boost + Solar Electric
- **Architecture mass estimated for each unique trajectory to help facilitate the strategic planning process**

Due to time limitations and the sheer magnitude of number of simulations to be run, only parametric mass sizing was implemented. Although the parametric results have been validated with results from more detailed assessments, the results contained herein should be used for comparative assessments only

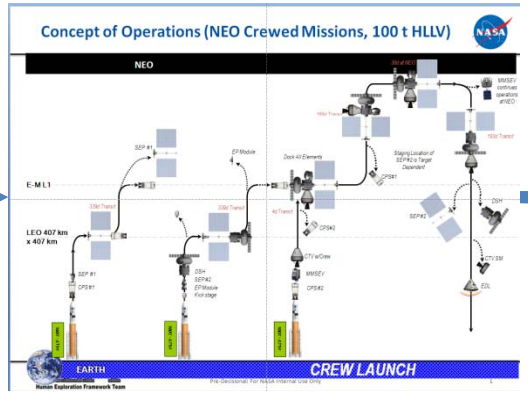
Applied Methodology

Trajectory Scans

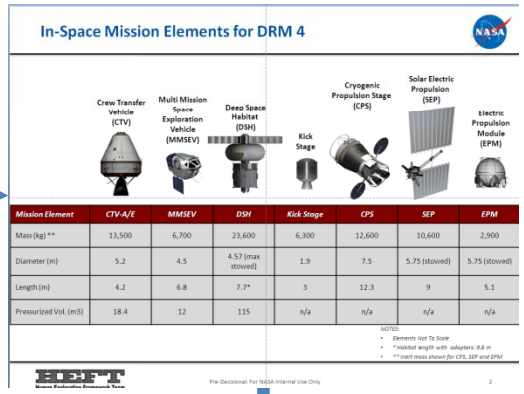


Star ID	Number	Name	Launch	DV (km/s)	TOF (d)	C3 (km2/s2)	Post\ DV (km/s)	Ast Arr DV	Ast Dep DV	Earth Ar DV
1397	3423321	2008 PW4	5/19/2033	11.523	210	22.407	7.341	4.37	2.676	0.25
1398	3423321	2008 PW4	4/29/2038	11.306	238	22.028	7.141	3.89	1.776	1.47
1399	3423321	2008 PW4	4/29/2038	10.185	252	22.028	6.019	3.89	2.098	0.03
1400	3426791	2008 RH1	2/21/2019	11.688	357	13.617	7.881	4.968	2.893	
1401	3426791	2008 RH1	2/28/2019	11.839	350	15.273	7.961	5.068	2.893	
1402	3426791	2008 RH1	9/19/2019	6.82	357	12.399	3.043	1.382	1.463	
1403	3426791	2008 RH1	12/3/2019	11.673	252	22.547	7.486	4.391	3.067	0.02
1404	3426791	2008 RH1	4/9/2020	11.569	357	7.75	8.02	4.52	3.5	
1405	3426791	2008 RH1	5/21/2020	11.865	343	7.099	8.345	4.908	3.437	
1406	3426791	2008 RH1	10/10/2030	11.928	322	22.792	7.731	3.752	3.955	0.02
1407	3426791	2008 RH1	9/12/2030	8.894	357	17.545	4.918	1.5	3.11	0.36
1408	3426791	2008 RH1	7/17/2031	11.613	287	23.334	7.393	3.965	3.408	
1409	3426791	2008 RH1	5/8/2031	11.344	357	15.806	7.443	3.837	3.606	
1410	3426791	2008 RH1	4/1/2032	11.538	322	23.605	7.307	2.082	5.19	0.03
1411	3426791	2008 RH1	4/1/2032	9.61	357	21.915	5.449	1.715	3.733	
1412	3427455	2008 SO	4/3/2031	11.707	175	23.432	7.483	2.583	4.9	
1413	3427455	2008 SO	4/3/2031	10.777	357	23.432	6.552	2.583	3.969	
1414	3429819	2008 TD2	10/17/2024	11.576	357	4.379	8.177	5.374	2.803	
1415	3429819	2008 TD2	4/10/2025	11.953	182	7.726	8.405	5.602	2.803	
1416	3430494	2008 TT26	4/28/2022	11.649	357	17.814	7.662	4.09	3.572	
1417	3430494	2008 TT26	5/12/2022	11.956	343	14.508	8.111	4.539	3.572	
1418	3430494	2008 TT26	4/21/2033	11.805	357	22.481	7.621	3.672	3.949	
1419	3438964	2008 VA15	10/1/2015	11.94	182	9.984	8.293	3.332	4.961	
1420	3438964	2008 VA15	10/8/2015	11.974	175	12.004	8.237	3.277	4.961	
1421	3438964	2008 VA15	10/8/2015	11.544	357	12.367	7.792	2.784	5.008	
1422	3439478	2008 WK	11/15/2035	11.986	168	15.892	8.082	2.978	5.104	
1423	3439478	2008 WK	11/15/2035	11.815	182	15.892	7.91	2.978	4.933	

Operational Concept



Mission Payload Definition



Mission Element	CTV-A/E	MMSEV	DSH	Kick Stage	CPS	SEP	EPM
Mass (kg) **	13,500	6,700	23,600	6,300	12,600	10,600	2,900
Diameter (m)	5.2	4.5	4.57 (max stowed)	1.9	7.5	5.75 (stowed)	5.75 (stowed)
Length (m)	4.2	6.8	7.7*	3	12.3	9	5.1
Pressurized Vol. (m3)	18.4	12	115	n/a	n/a	n/a	n/a

NOTES:
- Elements Not To Scale
- * Habitat length with adapters: 8.8 m
- ** Inert mass shown for CPS, SEP and EPM

Propulsion System Parametric Sizing

$$R = e^{\frac{\Delta V}{g * I_{sp}}}$$

$$Mass_{prop} = Mass_{payload} * (R-1) * \frac{(1 - f_{inert})}{1 - R * f_{inert}}$$

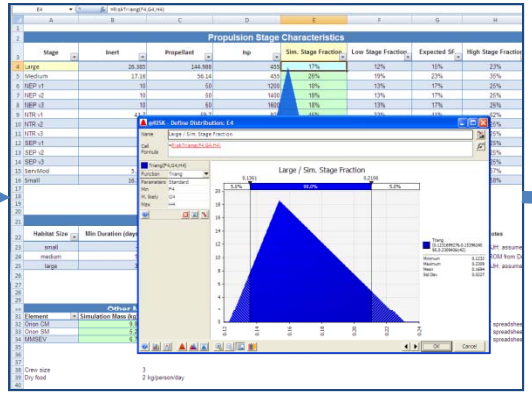
$$Mass_{inert} = Mass_{prop} * \frac{f_{inert}}{1 - f_{inert}}$$

$$Mass_{stage} = Mass_{prop} + Mass_{inert}$$

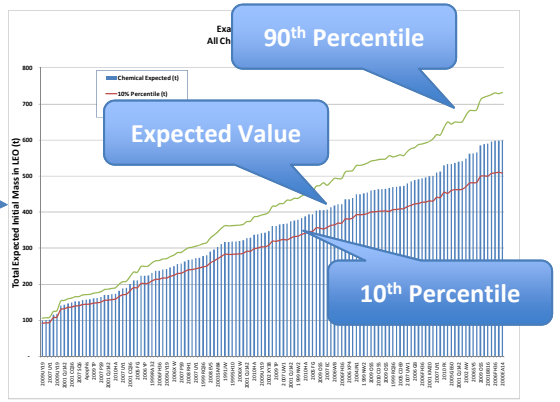
$$Mass_{phase} = Mass_{stage} + Mass_{payload}$$

Define Simulation Variables

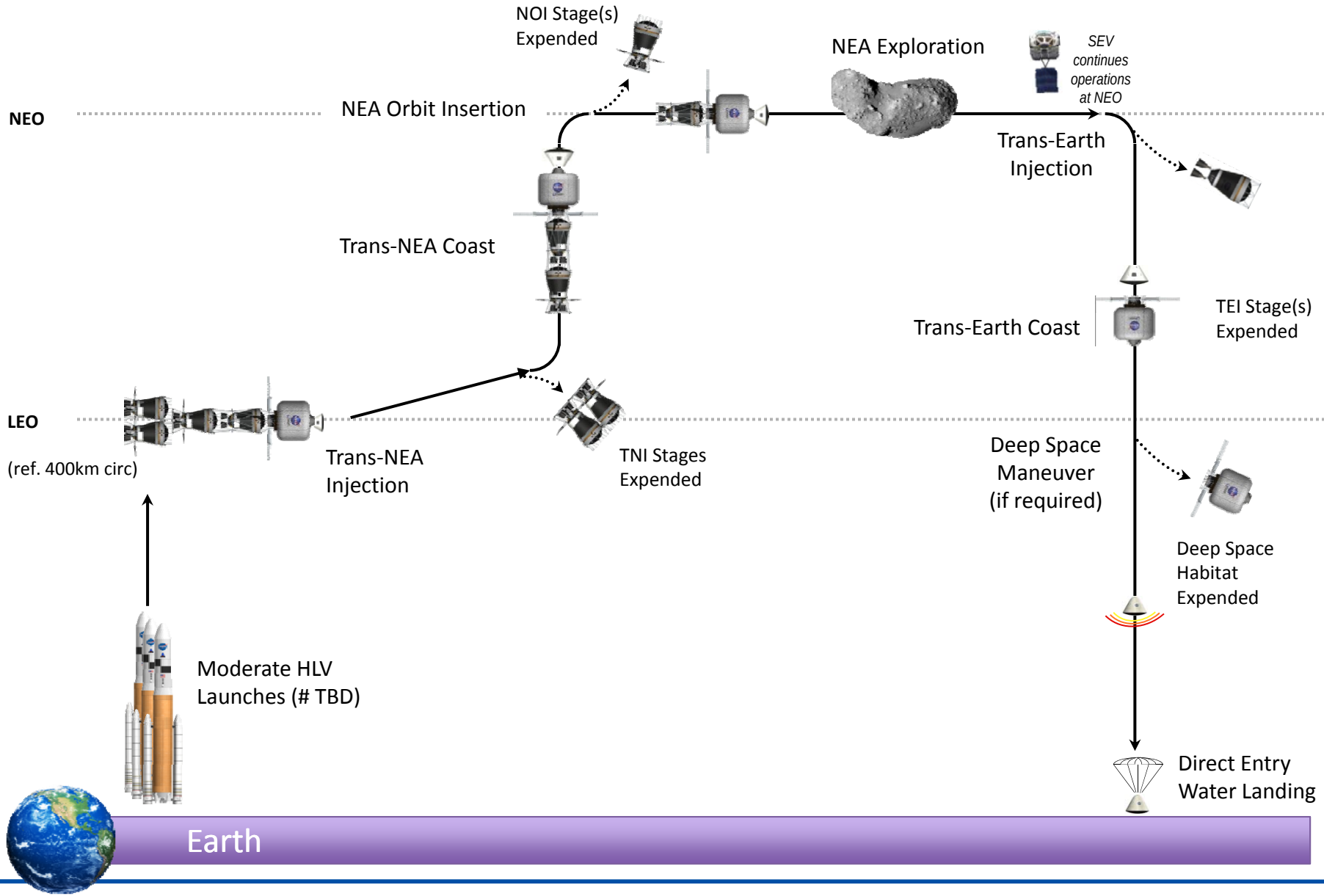
To account for early conceptual designs



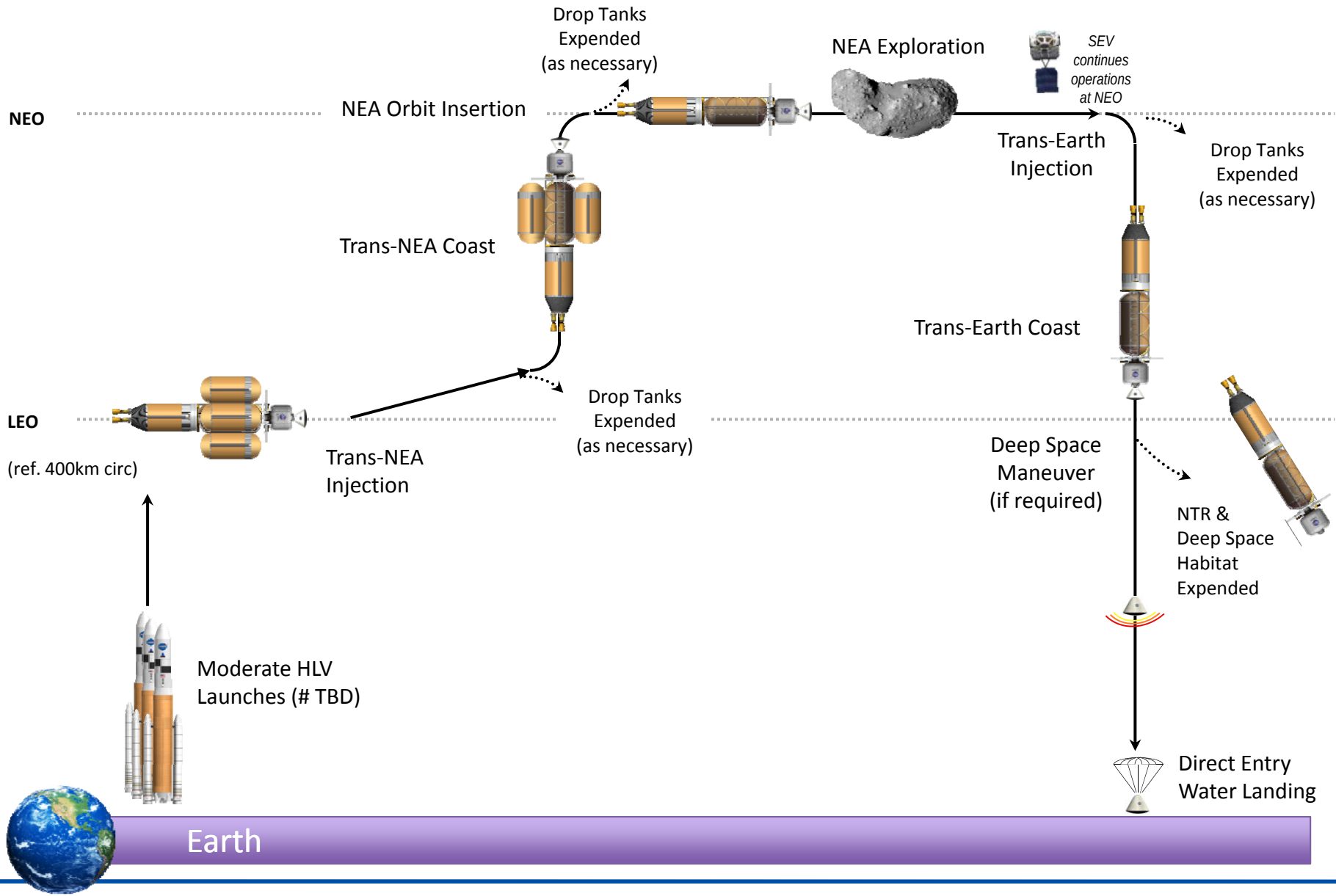
Simulation Results



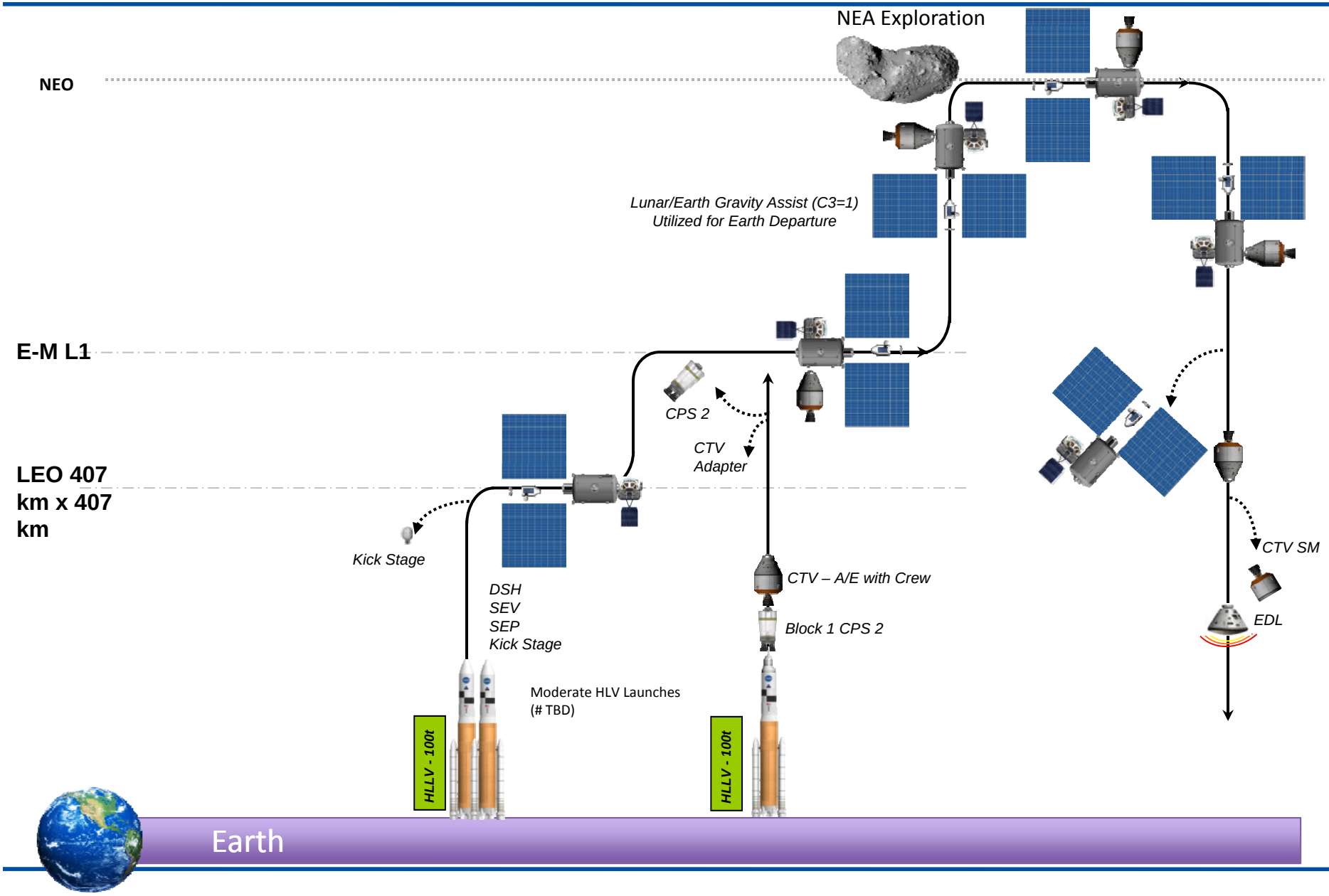
All Chemical NEA Mission Operations



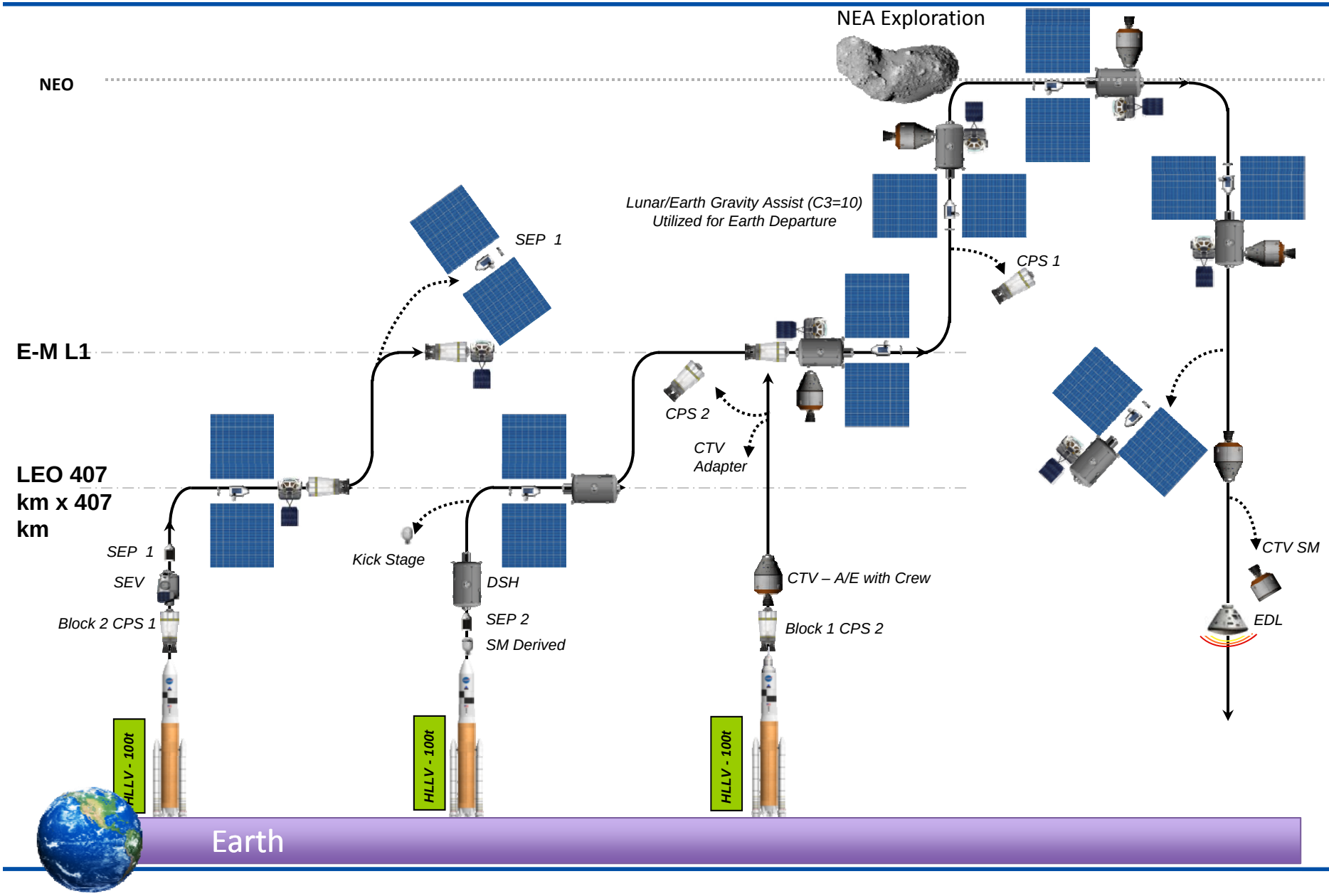
All Nuclear Thermal Propulsion NEA Mission Operations



SEP Only for Deep Space Mission Operations



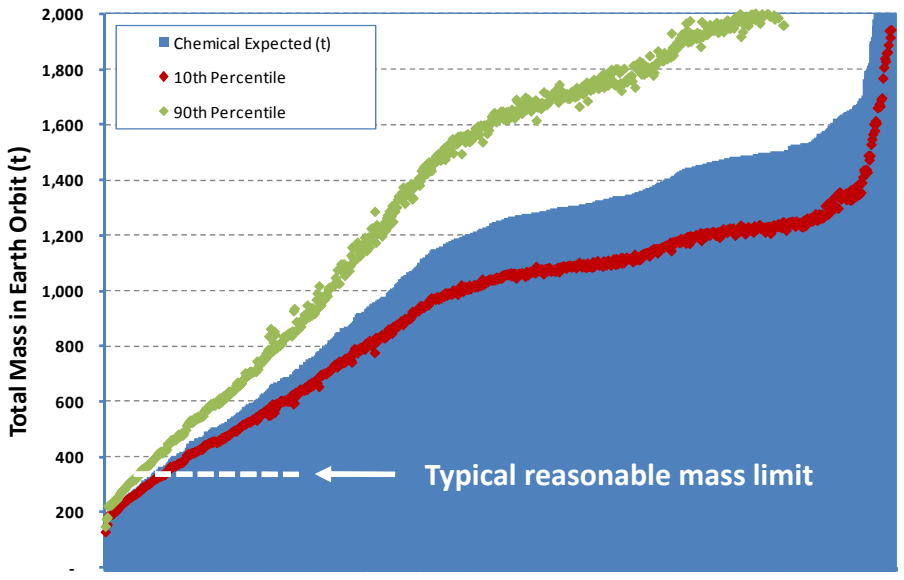
SEP/Chemical Hybrid NEA Mission Operations



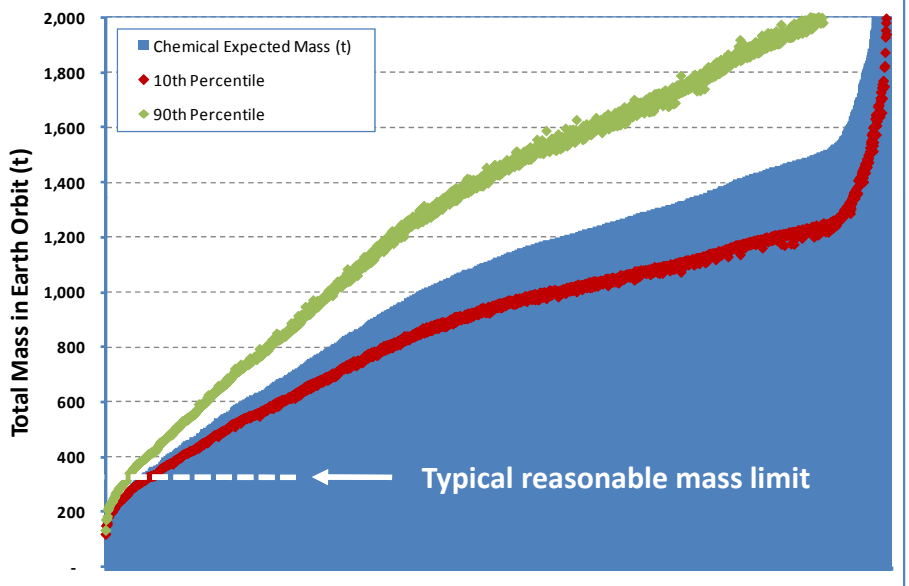
Example Mass Trends Between Datasets

All Chemical Propulsion Architecture

GSFC Dataset

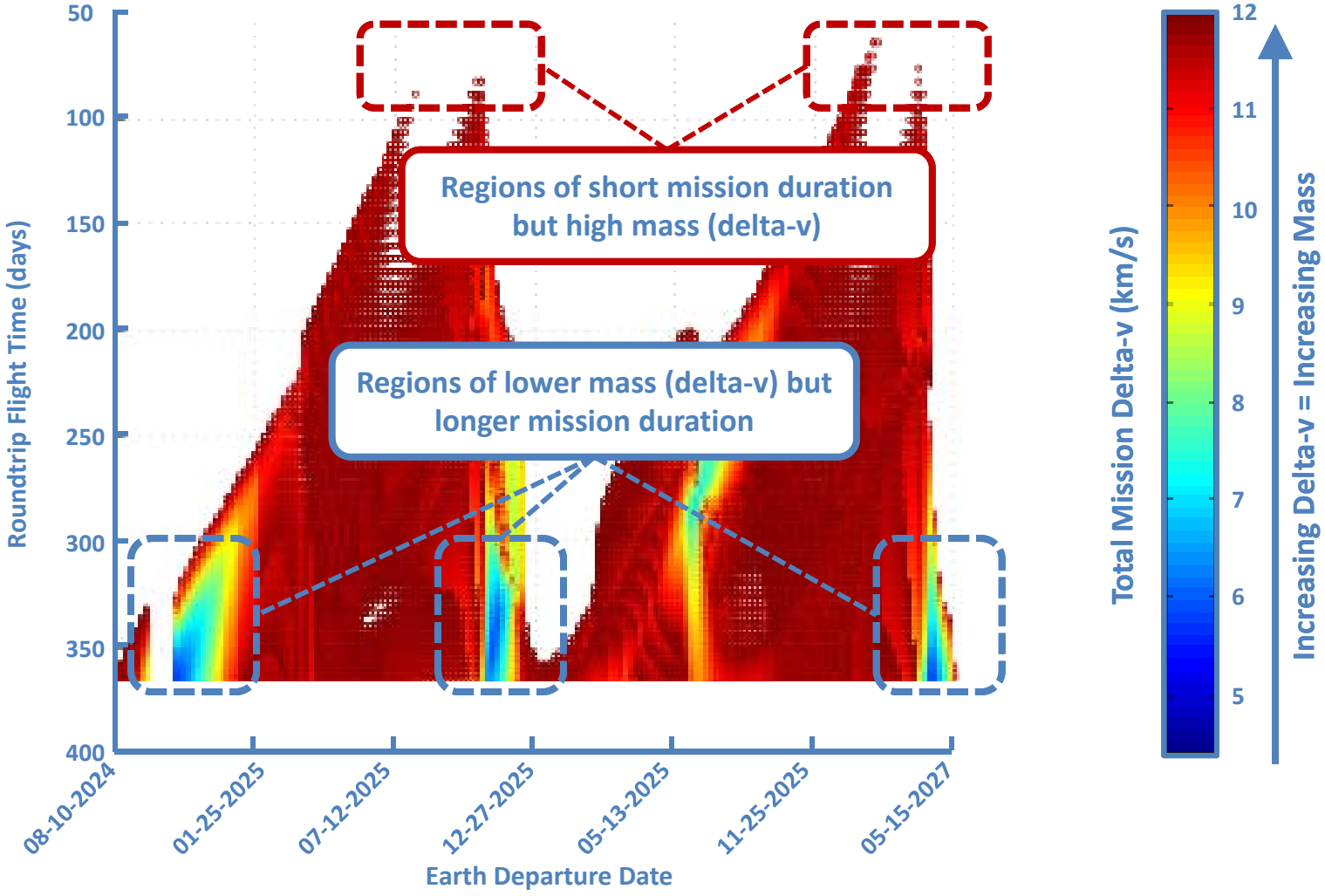


JPL Dataset



Example Sensitivity of Delta-v and Trip Time

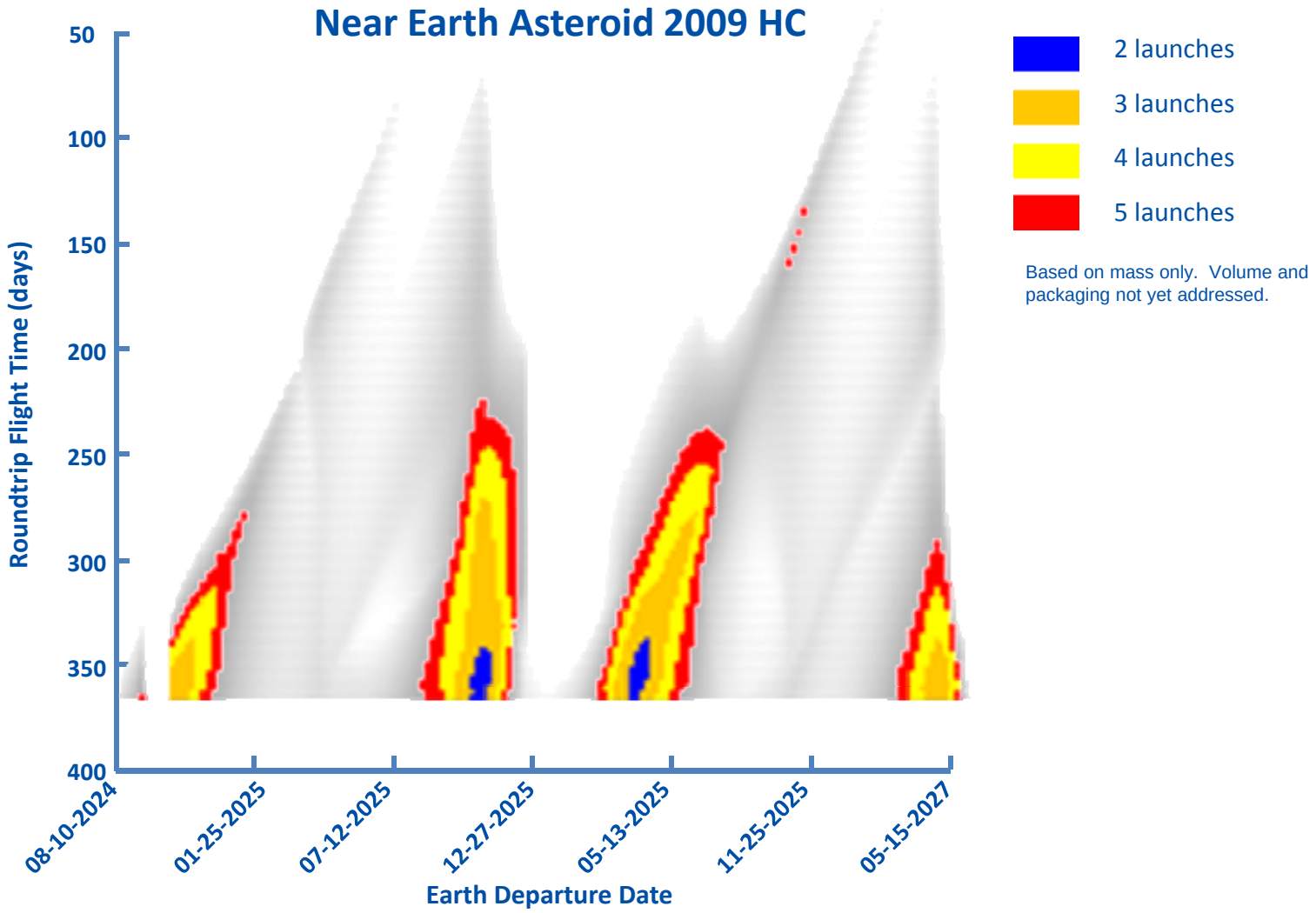
Near Earth Asteroid 2009 HC



Courtesy GSFC

Example Sensitivity of Number of Launches and Trip Time

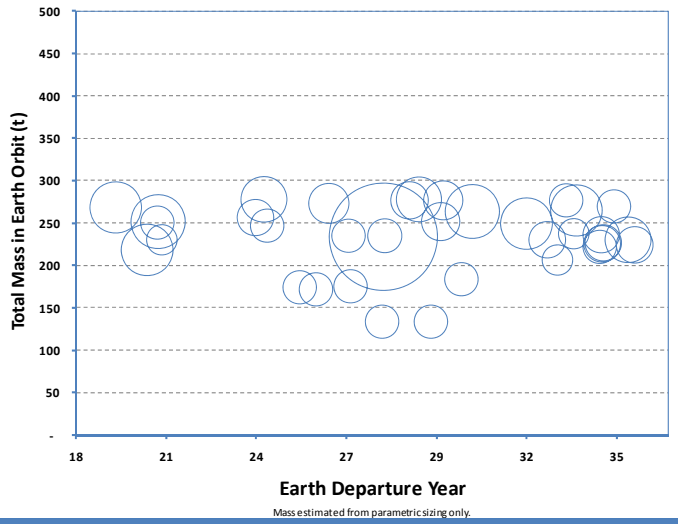
All Chemical Propulsion Architecture



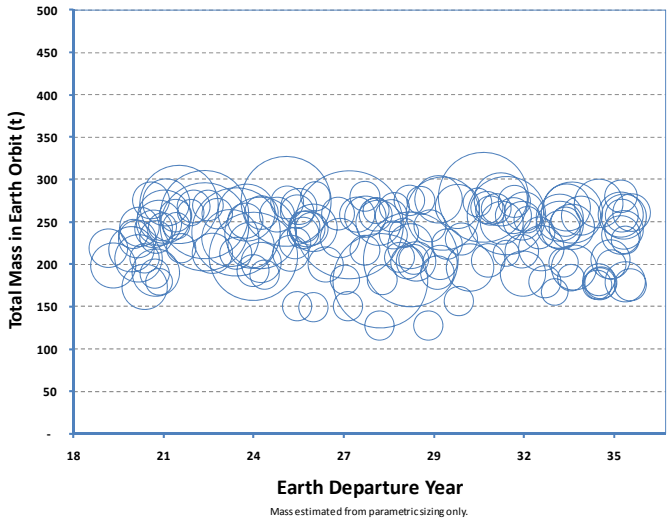
Example # of Expected Targets for Various Transportation Architectures

Circa 2020-2035, Asteroids > 30m, Approximately 3 Launches, < 1 Year Duration

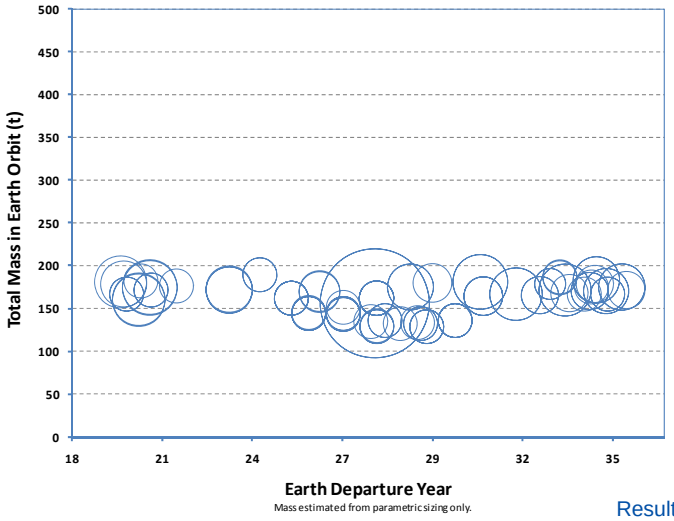
All Chemical Architecture



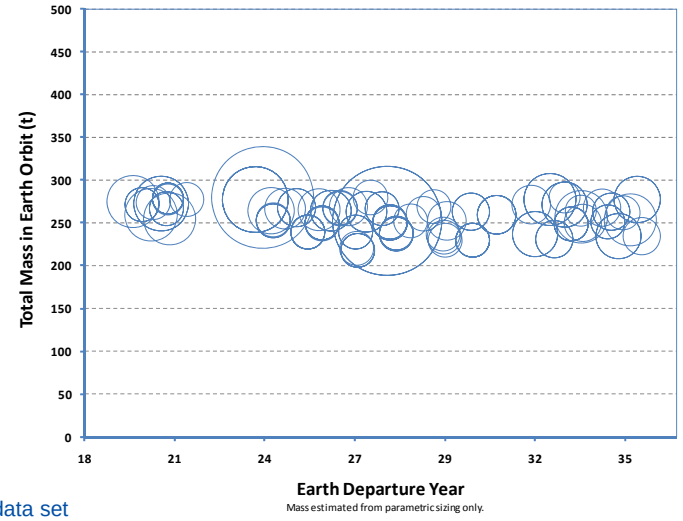
All NTR Architecture



All SEP for Deep Space



SEP/Chemical Architecture

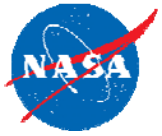


Results associated with the JPL data set

Summary

- Mission design and architectural assessments still under way
- No firm decisions yet on specific technologies or NEA targets have been made
- Key focus is on understanding the key capabilities and technologies required for a broad range of exploration architectures including human exploration of NEAs

Contributors



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